Chapter 6
Additional Environmental Improvement Opportunities

This chapter of the Cleaner Technologies Substitute Assessment (CTSA) identifies and qualitatively discusses techniques that can be used by printed wiring board (PWB) manufacturing facilities to prevent pollution, minimize waste, recycle and recover valuable resources, and control releases. The Pollution Prevention Act of 1990 set forth the following hierarchy to waste management in order of desirability:

- Pollution prevention at the source.
- Recycling in an environmentally safe manner.
- Treatment in an environmentally safe manner.
- Disposal or other release into the environment only as a last resort and in an environmentally safe manner.

This hierarchy has been adopted by EPA as the preferred method of waste management to reduce or eliminate potential releases by industry. The hierarchy reflects the common sense notion that preventing pollution is preferable to any subsequent response, be it recycling, treatment, or disposal. By preventing pollution we also eliminate potential transfers of the pollution across media (Kling, 1995).

The hierarchy also recognizes that pollution prevention is not always feasible and that other waste management methods are often required. When pollution prevention is not feasible, we should turn in order to recycling, treatment, and finally disposal if no other option remains. A manufacturing facility often combines pollution prevention techniques with these other approaches to effectively reduce emissions from a production process. While pollution prevention is clearly the most desirable, all of these methods contribute to overall environmental improvement (Kling, 1995).

This chapter focuses on the application of the waste management hierarchy to potential waste streams generated by the making holes conductive (MHC) process of the PWB industry. Techniques are identified, organized, and presented in an order corresponding to the hierarchy. Pollution prevention techniques are presented in Section 6.1, while methods for minimizing waste, recycling or recovering resources, and controlling releases are presented in Section 6.2. While the focus of this chapter is on the MHC line, many of the techniques described here can be applied to other processes used in PWB manufacturing. A series of pollution prevention case studies developed by the EPA DfE Program for the PWB industry present examples of the successful implementation of techniques available to industry (EPA, 1995a; EPA, 1995b; EPA, 1996a; EPA, 1996b; EPA, 1996c).

6.1 POLLUTION PREVENTION

Pollution prevention, defined in the Pollution Prevention Act of 1990, is the reduction in the amounts or hazards of pollution at the source and is often referred to as source reduction. Source reduction, also defined in the Pollution Prevention Act, is any practice which: 1) reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and 2) reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants. Source reduction includes equipment or technology modification, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control.

Current pollution prevention practices within the PWB industry were identified and data were collected through contact with industry personnel, extensive review of published accounts, and through the design and dissemination of two information requests to PWB manufacturers. The IPC Workplace Practices Questionnaire, conducted as part of this CTSA, specifically focused on the MHC process to identify important process parameters and operating practices for the various MHC technologies. For a breakdown of respondents by alternative, refer to Section 1.3.4 of the Introduction. Facility characteristics of respondents are presented in Section 3.2, Exposure Assessment. The questionnaire used in the IPC Workplace Practices Questionnaire is presented in Appendix A.

The Pollution Prevention and Control Technology Survey (hereafter referred to as the Pollution Prevention Survey) was designed to collect information about past and present pollution prevention procedures and control technologies for the entire PWB manufacturing process. This Survey was performed by the DfE PWB Project and is documented in the EPA publication, *Printed Wiring Board Pollution Prevention and Control: Analysis of Survey Results* (EPA, 1995c). The Survey results presented periodically throughout this chapter are compiled from responses to the Pollution Prevention Survey unless otherwise indicated. Results from the Pollution Prevention Survey pertaining to recycle or control technologies are presented in Section 6.2 of this chapter.

Opportunities for pollution prevention in PWB manufacturing were identified in each of the following areas:

- Management and personnel practices.
- Materials management and inventory control.
- Process improvements.

The successful implementation of pollution prevention practices can lead to reductions in waste treatment, pollution control, environmental compliance, and liability costs. Cost savings can result directly from pollution prevention techniques that minimize water usage, chemical consumption, and process waste generation.

6.1.1 Management and Personnel Practices

Pollution prevention is an ongoing activity that requires the efforts of both management and employees to achieve the best results. While management's commitment to reducing pollution is the foundation upon which a successful pollution prevention program is built, any pollution prevention measures taken are ultimately implemented by the process employees, making them an integral part of any pollution prevention effort. Management and employees must work together to form an effective pollution prevention program.

Approximately half (52.6 percent) of the PWB companies responding to the Pollution Prevention Survey reported having a formal pollution prevention policy statement while half (50 percent) of the survey respondents reported having a pollution prevention program. Over two thirds (68.4 percent) of PWB companies surveyed reported conducting employee education for pollution prevention.

The scope and depth of pollution prevention planning and the associated activities will vary with the size of the facility. While larger facilities may go through an entire pollution prevention planning exercise (as described below), smaller facilities may require as little as a commitment by the owner to pollution prevention along with cooperation and assistance from employees to meet any stated goals. A list of management and personnel practices that promote pollution prevention, along with their benefits, are listed in Table 6.1.

Table 6.1 Management and Personnel Practices Promoting Pollution Prevention

Method	Benefits
Create a company pollution prevention and waste reduction policy statement.	Communicates to employees and states publicly the company commitment to achieving pollution prevention and waste reduction goals.
Develop a written pollution prevention and waste reduction plan.	Communicates to employees how to accomplish the goals identified in the company's policy statement. Identifies in writing specific implementation steps for pollution prevention.
Provide periodic employee training on pollution prevention.	Educates employees on pollution prevention practices.
Make employees accountable for their pollution prevention performance and provide feedback on their performance.	Provides incentives to employees to improve pollution prevention performance.
Promote internal communication between management and employees.	Informs employees and facilitates input on pollution prevention from all levels of the company.
Implement total cost accounting or activity-based accounting system.	Identifies true costs of waste generation and the benefits of pollution prevention.

A company's commitment to pollution prevention begins with a pollution prevention and waste reduction policy statement. This statement, which is the company's public proclamation of its dedication to preventing pollution and reducing waste, should clearly state why a program is being undertaken, include specific pollution prevention and waste reduction goals, and assign responsibility for accomplishing those goals. The statement details to the public and to its employees the depth of the company's commitment to pollution prevention.

A pollution prevention plan is needed to detail how the pollution prevention and waste reduction goals described in the company's policy statement will be achieved. The pollution prevention plan builds on the company's policy statement by:

- Creating a list of waste streams and their point sources.
- Identifying opportunities for pollution prevention.
- Evaluating and prioritizing waste reduction options.
- Developing an implementation strategy for options that are feasible.
- Creating a timetable for pollution prevention implementation.
- Detailing a plan for measuring and evaluating pollution prevention and waste reduction progress.

The plan is best developed with input drawn from the experiences of a team of people selected from levels throughout the company. The team approach provides a variety of perspectives to pollution prevention and helps to identify pollution prevention opportunities and methods for implementing them. Team members should include representatives from management, supervisory personnel, and line workers who are familiar with the details of the daily operation of the process. The direct participation of employees in the development of the pollution prevention plan is important since it is the employees who are responsible for implementing the plan.

Data should be collected by performing a waste minimization assessment on the company or process being targeted. Once identified, pollution prevention options should be evaluated and prioritized based on their cost, feasibility of implementation, and their overall effectiveness of reducing waste. After an implementation strategy and timetable is established, the plan, along with expected benefits, should be presented to the remaining company employees to communicate the company's commitment to pollution prevention.

Once the pollution prevention plan has been finalized and implementation is ready to begin, employees must be given the skills to implement the plan. Training programs play an important role in educating process employees about current pollution prevention practices and opportunities. The goal of the training program is to educate each employee on how waste is generated, its effects on worker safety and the environment, possible methods for waste reduction, and on the overall benefits of pollution prevention.

Employee training should begin at the time of new employee orientation, introducing them to the company's pollution prevention plan, thus highlighting the company's dedication to reducing waste. More advanced training focusing on process operating procedures, potential sources of release, and pollution prevention practices already in place should be provided after a few weeks of work or when an employee starts a new position. Retraining employees periodically will keep them focused on the company's goal of pollution prevention.

Effective communication between management and employees is an important part of a successful pollution prevention program. Reports to employees on the progress of implementing pollution prevention recommendations, as well as the results of actions already taken, reiterate management's commitment to reducing waste, while keeping employees informed and intimately involved in the process. Employee input should also be solicited both during and after the creation of the pollution prevention plan to determine if any changes in the plan are warranted.

Assigning responsibility for each source of waste is an important step in closing the pollution prevention loop. Making individual employees and management accountable for chemical usage and waste generated within their process or department provides incentive for employees to reduce waste. The quantity of waste generated should be tracked and the results reported to employees who are accountable for the process generating the waste. Progress in pollution prevention should be an objective upon which employees will be evaluated during performance reviews, once again emphasizing the company's commitment to waste reduction.

Employee initiative and good performance in pollution prevention areas should be recognized and rewarded. Employee suggestions that prove feasible and cost effective should be implemented and the employee recognized either with a company commendation or with some kind of material award. These actions will ensure continued employee participation in the company's pollution prevention efforts.

Implementing an activity-based or total cost accounting system will identify the costs of waste generation that are typically hidden in overhead costs by standard accounting systems. These cost accounting methods identify cost drivers (activities) within the manufacturing process and assign the costs incurred through the operation of the process to the cost drivers. By identifying the cost drivers, manufacturers can correctly assess the true cost of waste generation and the benefits of any pollution prevention efforts.

6.1.2 Materials Management and Inventory Control

Materials management and inventory control focuses on how chemicals and materials flow through a facility in order to identify opportunities for pollution prevention. A proper materials management and inventory control program is a simple, cost-effective approach to preventing pollution. Table 6.2 presents materials management and inventory control methods that can be used to prevent pollution.

Table 6.2 Materials Management and Inventory Control Pollution Prevention Practices

Practice	Benefits
Minimize the amount of chemicals kept on the floor at one time.	Provides incentives to employees to use less chemicals.
Manage inventory on a first-in, first-out basis.	Reduces materials and disposal costs of expired chemicals.
Centralize responsibility for storing and distributing chemicals.	Provides incentives to employees to use less chemicals.
Store chemical products in closed, clearly marked containers.	Reduces materials loss; increases worker safety by reducing worker exposure.
Use a pump to transfer chemical products from stock to transportation container.	Reduces potential for accidental spills; reduces worker exposure.

Controlling inventory levels and limiting access to inventory are widely used practices in the PWB manufacturing industry (78.9 percent of Pollution Prevention Survey respondents). Keeping track of chemical usage and limiting the amount of chemicals on the process floor provides process operators an incentive to use the minimum quantity of chemical required to do the job. Using chemicals on a first-in/first-out basis reduces the time chemicals spend in storage and the amount of expired chemical that is disposed. Some companies have contracted with a specific chemical supplier to provide all of their process chemicals and manage their inventory. In exchange for the exclusive contract, the chemical supplier assumes many of the inventory management duties including managing the inventory, material safety data sheets (MSDSs), ordering the chemicals, distributing the chemicals throughout the plant, and disposing of spent chemicals and packaging (Brooman, 1996).

Chemical storage and handling practices also provide pollution prevention opportunities. Ensuring that all chemical containers are kept closed when not in use minimizes the amount of chemical lost through evaporation or volatilization. When transferring chemicals from container to container, utilizing a hand pump can reduce the amount of chemical spillage. These simple techniques not only result in less chemical usage representing a cost savings, but also result in reduced worker exposure and an improved worker environment.

6.1.3 Process Improvements

Improving the efficiency of a production process can significantly reduce waste generation at the source. Process improvements include process or procedural changes in operations carried out by employees, process equipment modification or automation, and redesign of the process altogether. Process improvements that lead to pollution prevention in the MHC process are categorized by the following goals:

- Extend chemical bath life.
- Reduce water consumption.
- Improve process efficiency through automation.

Pollution prevention through process improvement does not always have to be expensive. In fact, some of the most cost-effective pollution prevention techniques are simple, inexpensive changes in production procedures. Process improvements that help achieve the goals listed above, along with their benefits, are discussed in detail in the sections below.

Extend Chemical Bath Life

The MHC process involves the extensive use of chemicals, many of which are costly and pose a hazard to human health and the environment. Improvements in the efficient usage of these chemicals can occur by accomplishing the following:

- Reducing chemical bath contamination.
- Reducing chemical bath drag-out.
- Improving bath maintenance.

Inefficiencies in the use of chemicals can result in increased chemical usage, higher operating costs, increased releases to the environment, and increased worker exposure. Techniques to improve the efficient use of chemicals by the MHC and other PWB process steps are discussed in detail below.

Reduce Bath Contaminants. The introduction of contaminants to a chemical bath will affect its performance and significantly shorten the life of the chemical bath. Bath contaminants include chemicals dragged-in from previous chemical baths, chemical reaction by-products, and particulate matter which may be introduced to the bath from the air. Process baths are replaced when impurities reach a level where they degrade product quality to an unacceptable level. Any measure that prevents the introduction of impurities will not only result in better bath performance, but also will reduce chemical usage and generate less waste. Table 6.3 presents pollution prevention methods for reducing bath contamination.

Table 6.3 Pollution Prevention Practices to Reduce Bath Contaminants

Practices	Benefits
Improve the efficiency of the water rinse system.	Rinses off any residual bath chemistries and dislodges any particulate matter from panels and racks.
Use distilled or deionized water during chemical bath make-up.	Reduces chemical contamination resulting from water impurities.
Maintain and rebuild panel racks.	Prevents the build-up of deposits and corrosion that can dislodge or dissolve into chemical baths.
Clean process tanks efficiently before new bath make-up.	Prevents contamination of the new bath from residual spent bath chemistries.
Utilize chemical bath covers when process baths are not in operation.	Reduces the introduction of unwanted airborne particulate matter; prevents evaporation or volatilization of bath chemistries.
Filter contaminants continuously from process baths.	Prevents the build-up of any contaminants.

Thorough and efficient water rinsing of process panels and the racks that carry them is crucial to preventing harmful chemical drag-in and to prolonging the life span of the chemical baths. The results of the IPC Workplace Practices Questionnaire indicate that nearly every chemical bath in the MHC process is preceded by at least one water rinse tank. Improved rinsing can be achieved by using spray rinses, panel and/or water agitation, warm water, or by several other methods that do not require the use of a greater volume of water. A more detailed discussion of these methods is presented in the reduced water consumption portion in this section.

A rack maintenance program is also an important part of reducing chemical bath contamination and is practiced by 87 percent of the respondents to the Pollution Prevention Survey. By cleaning panel racks regularly and replacing corroded metal parts, preferably with parts of plastic or stainless steel, chemical deposition and build-up can be minimized. Respondents to the IPC Workplace Practices Questionnaire typically perform rack cleaning using a chemical solution, usually acid. Mechanical methods, such as peeling or filing away the majority of any metal deposits before applying a weak acid solution, can be used to prevent pollution by reducing the quantity of acid required. An added benefit is that the reclaimed metal can be sold or reused in the process.

According to the IPC Workplace Practices Questionnaire, 42 percent of the respondents reported using bath covers on at least some of their baths during periods when the MHC process was not operating. Respondents were not specifically questioned about the other methods for reducing bath contamination described above; consequently, no information was collected.

Chemical Bath Drag-Out Reduction. The primary loss of bath chemicals during the operation of the MHC process comes from chemical bath drag-out (Bayes, 1996). This loss occurs as the rack full of panels is being removed from the bath, dragging with it a film of chemical solution still coating the panels. The drag-out is then typically rinsed from the panels by a water rinse tank, making bath drag-out the primary source of chemical contaminant introduction into the MHC rinse water. In some cases, however, the panels are deposited directly into the next process bath without first being rinsed (e.g., predip followed directly by palladium catalyst in tin-palladium process).

Techniques that minimize bath drag-out also prevent the premature reduction of bath chemical concentration, extending the useful life of a bath. In addition to extended bath life, minimizing or recovering drag-out losses also has the following effects:

- Requires less rinse water.
- Minimizes bath chemical usage.
- Reduces chemical waste.
- Requires less water treatment chemical usage.

Methods for reducing or recovering chemical bath drag-out are presented in Table 6.4 and then discussed below.

The most common methods of drag-out control employed by respondents to the Pollution Prevention Survey are slow panel removal from the bath (52.6 percent) and increased panel drainage time (76.3 percent). Removing the panels slowly from the bath allows the surface tension of the solution to remove much of the residual chemical from the panels. Most of the remaining chemicals can be removed from the panel surfaces by increasing the time allowed for the panels to drain over the process bath. Briefly agitating the panels directly after being removed from the tank can also help dislodge chemicals trapped in panel through-holes and result in better drainage. All three methods require no capital investment and when practiced individually or in combination, these techniques are effective methods for reducing drag-out.

Drain boards catch drag-out chemicals that drip from panels as they are transported to the next process step. The chemicals are then returned to the original process bath. Chemical loss due to splashing can be prevented by the use of drip shields, which are plastic panels that extend the wall height of the process tank. Both drain boards and drip shields are inexpensive, effective drag-out control options. Unlike drip shields, however, space between process steps is required to install drain boards, making them impractical where process space is an issue.

Table 6.4 Methods for Reducing Chemical Bath Drag-Out

Methods	Benefits
Remove panels slowly from process baths.	Reduces the quantity of residual chemical on panel surfaces.
Increase panel drainage time over process bath.	Allows a greater volume of residual bath chemistries to drip from the panel back into the process bath.
Agitate panels briefly while draining.	Dislodges trapped bath chemistries from drilled through-holes.
Install drain boards.	Collects and returns drag-out to process baths.
Install drip shields between process baths.	Prevents bath chemical loss due to splashing.
Add static drag-out tanks/drip tanks to process line where needed.	Recovers chemical drag-out for use in bath replenishment.
Utilize non-ionic wetting agents in the process bath chemistries.	Reduces surface tension of bath solutions, thereby reducing residual chemicals on panel surfaces.
Utilize air knives directly after process bath in conveyorized system.[a]	Blows residual process chemistries from process panels which are recaptured and returned to process bath.
Decrease process bath viscosity.	Reduces quantity of chemical that adheres to panel surface.
Employ fog rinses/spray rinses over heated baths.	Rinses drag-out from the panels as they are removed from the solution.

[a] May not be a viable pollution prevention technique unless system is fully enclosed to prevent worker exposure to bath chemicals introduced to the air.

Much of the chemical solution lost to drag-out can be recovered through the use of either static drag-out tanks or drip tanks. A static drag-out tank is a batch water bath that immediately follows the process bath from which the drag-out occurs. The panels are submerged and agitated in the static rinse water, washing the residual chemicals from the panel's surface. When sufficiently concentrated, the rinse water and chemical mixture can be used to replenish the original bath. Drip tanks are similar to static drag-out tanks except that they contain no water. The drip tank collects chemical drag-out which can then be returned to the process bath. Static drag-out tanks are most suitably used in conjunction with heated process baths which lose water by evaporation, requiring frequent replacement.

Bath viscosity can be lowered by increasing bath temperature, decreasing bath concentration, or both. Both of these methods may negatively affect overall process performance if done in excess, however, and the chemical supplier should be consulted. In addition, increased bath temperatures can increase chemical volatilization and worker exposure. Energy implications of higher temperature baths should also be considered and are discussed in Section 5.2.

Bath Maintenance Improvements. The MHC process and other wet chemistry processes in PWB manufacturing are series of complex, carefully balanced and formulated chemical mixtures, each one designed to operate at specific conditions, working together to perform an overall function. A bath testing and control program is essential in preventing the chemical breakdown of process baths, thus extending their useful lives and preventing their premature disposal. The premature disposal of process chemistries results in increased chemical costs for both bath and treatment chemicals, prolonged process down-time, and increased process waste.

Bath maintenance, or control, refers to maintaining a process bath in peak operating condition by identifying and controlling key operating parameters, such as bath temperature, individual chemical concentrations, pH, and the concentration of contaminants. Proper control of bath operating parameters will result in more consistent bath operation, less water usage, and better, more consistent quality of work.

According to Pollution Prevention Survey respondents, the majority of PWB manufacturing facilities (92.1 percent) have a preventative bath maintenance program already in place. Typical bath maintenance methods and their benefits are presented in Table 6.5 below.

Table 6.5 Bath Maintenance Improvement Methods To Extend Bath Life

Methods	Benefits
Monitor bath chemistries by testing frequently.	Determines if process bath is operating within recommended parameters.
Replace process baths according to chemical testing.	Prevents premature chemical bath replacement of good process baths.
Maintain operating chemical balance through chemical additions according to testing.	Maintains recommended chemical concentrations through periodic chemical replenishment as required.
Filter process baths continuously.	Prevents the build-up of harmful impurities that may shorten bath life.
Employ steady state technologies.	Maintains steady state operating conditions by filtering precipitates or regenerating bath solutions continuously.
Install automated/statistical process control system.	Provides detailed analytical data of process operating parameters, facilitating more efficient process operation.
Utilize temperature control devices.	Regulates bath temperatures to maintain optimum operating conditions.
Utilize bath covers.	Reduces process bath losses to evaporation and volatilization.

Frequent monitoring and adjustment of the various chemical concentrations within a process bath are the foundations on which a good bath maintenance program is built. Monitoring is done by regularly testing the bath concentrations of key chemicals to ensure that the bath is chemically balanced. If chemical concentrations are outside of the operating levels recommended by the supplier, a volume of chemical is added to the bath to bring it back into balance. When the concentration of contaminants reaches an established critical level, or some other criteria reported by the supplier, the bath is disposed of and replaced with a new bath.

Bath testing and adjustment can be performed manually or with an automated system that can perform both functions. Either way, controlling the bath through regular testing and bath additions is an inexpensive, effective method for extending bath life and reducing pollution. Nearly all of the PWB facilities surveyed (97.4 percent) report testing chemical bath concentrations.

Bath replacement should be based upon chemical testing, instead of some other predetermined criteria. Predetermined criteria, such as times or production volumes, are often given by suppliers as safe guidelines for bath replacement for facilities that do not regularly test their process baths. These criteria are conservative estimates of the effective life of the process bath, but can be exceeded with a proper bath testing and maintenance program. By replacing the process bath only when chemical testing indicates it is required, bath life can be extended while chemical usage and waste are reduced. Most (92.1 percent) of the surveyed PWB facilities reported replacing their process baths only when testing indicated.

The build-up of contaminants in a process bath will eventually require the bath to be replaced. Bath contaminants can be solid matter, such as particulate matter and precipitates, or undesired chemical species in solution, such as reaction byproducts or drag-in chemicals. An effective method of extending bath life is to continuously filter the process bath to remove undesired bath constituents. Installing standard cartridge or bag filters which remove solid impurities from the bath is another inexpensive, yet effective method to extend bath life.

Some baths may be maintained at steady state conditions using readily obtainable systems capable of regenerating or filtering process bath chemistries. For example, a system that continuously filters the copper sulfate precipitate from peroxide-sulfuric microetch baths can be used to maintain the microetch bath on a MHC process line, providing a recyclable precipitate. Regeneration techniques can be used to continuously regenerate both alkaline and cupric chloride etchants. Maintaining steady state conditions keeps a bath within the optimal operating conditions resulting in extended bath life (Edwards, 1996).

Statistical process control (SPC) is a method of analyzing the current and past performance of a process bath, using chemical testing results and operating condition records to optimize future bath performance. SPC will lead to more efficient bath operation and extended bath life by indicating when a bath needs maintenance through the tracking and analysis of individual operating parameters and their effect on past performance (Fehrer, 1996). Only one quarter (26.3 percent) of the survey respondents reported using a SPC system.

Many of the MHC process baths are heated, making temperature control an important necessity for proper bath operation. If bath temperature is not controlled properly, the bath may not be hot enough to perform its function, or may become too hot, leading to chemical and water losses due to evaporation or volatilization. The bath chemicals that remain become more concentrated, resulting in increased chemical loss to drag-out. By installing thermostats on all heated process baths, solution temperature will be kept constant, reducing waste generation and chemical and energy use, and saving money through decreased energy use, chemical use, and waste treatment costs.

Another method of limiting evaporative losses from process baths is to cover the surface of the solution with floating plastic balls that will not react with the process solution. The plastic balls, which do not interfere with the work pieces being processed, prevent the evaporation of the bath solution by limiting the surface area of solution exposed to the air. One facility uses ping pong balls which are made from polystyrene to minimize losses from the electroless copper bath. Hexagonal-shaped balls are now available that leave even less surface area exposed to the air (Brooman, 1996). This method is especially effective for higher temperature process baths where evaporative losses tend to be high. This method is inexpensive, easy to utilize, and will decrease the air emissions from the bath, limiting the amount of operator exposure to the chemicals.

Reduced Water Consumption

Contaminated rinse water is the primary source of heavy metal ions discharged to waste treatment processes from the MHC process and other wet chemistry process lines (Bayes, 1996). These contaminants, which are introduced to the rinse water through chemical drag-out, must be treated and removed from the water before it can be reused in the process or discharged to the sewer. Because rinsing is often an uncontrolled portion of the process, large quantities of water are consumed and treated unnecessarily. Reducing the amount of water used by the MHC process has the following benefits:

- Decreases water and sewage costs.
- Reduces wastewater treatment requirements, resulting in less treatment chemical usage and reduced operating costs.
- Reduces the volume of sludge generated from wastewater treatment.
- Improves opportunities to recover process chemicals from more concentrated waste streams.

The MHC process line consists of a series of chemical baths, which are typically separated by at least one, and sometimes more, water rinse steps. These water rinse steps account for virtually all of the water used during the operation of the MHC line. The water baths act as a buffer, dissolving or displacing any residual drag-in chemicals from the panels surface. The rinse baths prevent contamination of subsequent baths while creating a clean surface for future chemical activity.

Improper rinsing does not only lead to shortened bath life through increased drag-in, as discussed previously, but can also lead to a host of problems affecting product quality, such as peeling, blistering and staining. Insufficient rinsing of panels can lead to increased chemical drag-in quantities and will fail to provide a clean panel surface for subsequent chemical activity. Excessive water rinsing, done by exposing the panels too long to water rinsing, can lead to oxidation of the copper surface and may result in peeling, blistering, and staining. To avoid insufficient rinsing, manufacturers often use greater water flow rates than are necessary, instead of using more efficient rinsing methods that reduce water consumption but may be more expensive to implement. These practices were found to be true among survey respondents, where facilities with low water and sewage costs typically used much larger amounts of water than comparable facilities with high water and sewer costs.

Many techniques are available that can reduce the amount of water consumed while rinsing. These techniques are categorized by the following:

- Methods to control water flow.
- Techniques to improve water rinse efficiency.
- Good housekeeping practices.

Flow control methods focus on controlling the flow of water, either by limiting the maximum rate that water is allowed to flow into the rinse system, or by stopping and starting the water flow as it is needed. These methods seek to limit the total water usage while ensuring that sufficient water is made available to cleanse the PWB panels. Examples of these techniques include the use of flow restrictors or smaller diameter piping to limit the maximum flow of water, and control valves that provide water to the rinse baths only when it is needed. Control valves can be either manually operated by an employee, or automated using some kind of sensing device such as conductivity meters, pH meters, or parts sensors. All of the methods are effective water reduction techniques that can be easily installed.

Pollution prevention techniques directed at improving water efficiency in the rinse system seek to control or influence the physical interaction between the water and the panels. This can be done by increasing bath turbulence, improving water quality, or by using a more efficient rinse configuration. All of these methods, discussed below, seek to improve rinsing performance while using less water.

Increasing bath turbulence can be accomplished through the use of ultrasonics, panel agitation, or air sparging. All of these agitation methods create turbulence in the bath, increasing contact between the water and the part, thereby accelerating the rate that residual chemicals are removed from the surface. Agitating the bath also keeps the water volume well mixed, distributing contaminants throughout the bath and preventing concentrations of contaminants from becoming trapped. However, agitating the bath can also increase air emissions from the bath unless pollution prevention measures are used to reduce air losses.

Water quality can be improved by using distilled or deionized water for rinsing instead of tap water that may include impurities such as carbonate and phosphate precipitates, calcium, fluoride, and iron. Finally, utilizing more efficient rinse configurations such as countercurrent rinse stages, spray rinses, or fog rinses will increase the overall efficiency of the MHC rinse system while reducing the volume of wastewater generated. PWB manufacturers often use multiple rinse water stages between chemical process steps to facilitate better rinsing. The first rinse stage removes the majority of residual chemicals and contaminants, while subsequent rinse stages remove any remaining chemicals. Counter-current or cascade rinse systems minimize water use by feeding the water effluent from the cleanest rinse tank, usually at the end of the cascade, into the next cleanest rinse stage, and so on, until the effluent from the most contaminated, initial rinse stage is sent for treatment or recycle.

Good housekeeping practices focus on keeping the process equipment in good repair and fixing or replacing leaky pipes, pumps, and hoses. These practices can also include installing devices such as spring loaded hose nozzles that shut off when not in use, or water control timers that shut off water flow in case of employee error. These practices often require little investment and are effective in preventing unnecessary water usage. For a more detailed discussion on methods of improving water rinse efficiency and reducing water consumption, refer to Section 5.1, Resource Conservation.

Improve Process Efficiency Through Automation

The operation of the MHC process presents several opportunities for important and integral portions of the process to become automated. By automating important functions, operator inconsistencies can be eliminated allowing the process to be operated more efficiently. Automation can lead to the prevention of pollution by:

- Gaining a greater control of process operating parameters.
- Performing the automated function more consistently and efficiently.
- Eliminating operator errors.
- Making the process compatible with newer and cleaner processes designed to be operated with an automated system.

Automating a part of the MHC process can be expensive. The purchase of some automated equipment can require a significant initial investment, which may prevent small companies from automating. Other costs that may be incurred include installing the equipment, training employees, any lost production due to process down-time, and the cost of redesigning other processes to be compatible with the new system. Although it may be expensive, the benefits of automation on productivity and waste reduction will result in a more efficient process that can save money over the long run.

Installation of automated equipment such as a rack or panel transportation system, chemical sampling equipment, or an automated system to make chemical additions can have a major impact on the quantity of pollution generated during the day-to-day operation of the MHC process and can also reduce worker exposure. MHC process steps or functions that can be automated effectively include:

- Rack transportation.
- Bath maintenance.
- Water flow control.

Rack transportation systems present an excellent opportunity for automation, due to the repetitive nature of transporting panel racks. Various levels of automation are available ranging from a manually operated vertical hoist to a computer controlled robotic arm. All of these methods allow for greater process control over panel movement through the MHC process line. By building in drag-out reduction methods such as slower panel withdraw and extended drainage times into the panel movement system, bath chemical loss and water contamination can be greatly reduced.

Automating bath maintenance testing and chemical additions can result in longer bath life and reduced waste. These systems monitor bath solutions by regularly testing bath chemistries for key contaminants and concentrations. The system then adjusts the process bath by making small chemical additions, as needed, to keep contaminant build-up to a minimum and the process bath operating as directed. The resulting process bath operates more efficiently, resulting in prolonged bath life, less chemical waste, reduced chemical cost, and reduced drag-out.

Controlling rinse water flow is an inexpensive process function to automate. Techniques for controlling rinse water flow were discussed previously. The reduction in fresh water usage as a result of automating these techniques will not only reduce water costs, but will also result in reduced treatment chemical usage and less sludge.

A conveyorized system integrates many of the methods described above into a complete automated MHC system. The system utilizes a series of process stages connected by a horizontal conveyor to transport the PWB panels through the MHC process. Drag-out is greatly reduced due, in part, to the separate process stages, and to the vertical alignment of the drilled holes that trap less chemicals. Since drag-out is reduced, much less rinse water is required to cleanse the panel surfaces, resulting in reduced water and treatment costs. A single water tank is sufficient between process baths where multiple stages may be required in a non-conveyorized process, thus dramatically reducing the number of process stages required, resulting in a much shorter cycle time and reduced floor space requirements. The enclosed process stages limit evaporative losses, reducing chemical costs, while also reducing the amount of chemical to which an employee is exposed. Several MHC alternative chemistry processes have been designed to operate effectively using this type of conveyorized system.

A conveyorized system should also take advantage of other pollution prevention techniques, such as water flow controllers, bath maintenance techniques and other methods discussed throughout this module, to further reduce waste. By integrating all of these methods together into a single MHC system, the process operates more efficiently, reducing water and chemical consumption, resulting in less process waste and employee exposure.

Segregate Wastewater Streams to Reduce Sludge Generation. Another type of process improvement to prevent pollution relates to segregating the wastewater streams generated by MHC and other PWB manufacturers process steps. The segregation of wastewater streams is a simple and cost-effective pollution prevention technique for the MHC process. In a typical PWB facility, wastewater streams from different process steps are often combined and then treated by an on-site wastewater treatment process to comply with local discharge limits.

Some waste streams from the MHC process, however, may contain chelating agents. These chelators, which permit metal ions to remain dissolved in solution at high pH levels, must first be broken down chemically before the waste stream can be treated and the heavy metal ions removed. Treatment of waste containing chelators requires extra treatment steps or more active chemicals to break down the chelating agents and precipitate out the heavy metal ions from the remaining water effluent. Because the chelator-bearing streams are combined with other non-chelated streams before being treated, a larger volume of waste must be treated for chelators than is necessary, which also results in a larger volume of sludge.

To minimize the amount of treatment chemical used and sludge produced, the chelated waste streams should be segregated from the other non-chelated wastes and collected in a storage tank. When enough waste has been collected, the chelated wastes should be batch treated to breakdown the chelator and remove the heavy metals. The non-chelated waste streams can then be treated by the on-site wastewater treatment facility without additional consideration. By segregating and batch treating the chelated heavy metal wastes from other non-hazardous waste streams, the volume of waste undergoing additional treatment is minimized and treatment chemical usage and sludge generation reduced.

6.2 RECYCLE, RECOVERY, AND CONTROL TECHNOLOGIES ASSESSMENT

While pollution prevention is the preferred method of waste management, the waste management hierarchy recognizes that pollution prevention is not always feasible. Companies often supplement their pollution prevention efforts with additional waste management techniques to further reduce emissions. These techniques, presented in order of preference, include recycling, treatment, and disposal. This section presents waste management techniques typically used by the PWB industry in the MHC process to minimize waste, recycle or recover valuable process resources, and to control emissions to water and air.

6.2.1 Recycle and Resource Recovery Opportunities

PWB manufacturers have begun to reevaluate the merits of recycle and recovery technologies because of more stringent effluent pretreatment regulations. Recycling is the in-process recovery of process material effluent, either on-site or off-site, which would otherwise become a solid waste, air emission, or a wastewater stream. Metals recycling and recovery processes have become more economical to operate due to the increased cost of managing sludge containing heavy metals under stricter regulatory requirements. Technologies that recycle water from waste streams concentrate the final effluent making subsequent treatment more efficient, thus reducing the volume of waste generated along with overall water and sewer costs. As a result, these technologies are being used more frequently by industry to recycle or recover valuable process resources while also minimizing the volume of waste that is sent to disposal. This trend was supported by the respondents of the *Printed Wiring Board Pollution Prevention and Control: Analysis of Survey Results* (EPA, 1995c), 76 percent of whom reported using some type of recycle or resource recovery technology.

Recycle and resource recovery technologies include those that recover materials from waste streams before disposal or recycle waste streams for reuse in another process. Opportunities for both types of technologies exist within the MHC process. Rinse water can be recycled and reused in further rinsing operations while copper can be recovered from waste streams before disposal and sold to a metals reclaimer. These recycle and recovery technologies may be either in-line (dedicated and built into the process flow of a specific process line) or at-line (employed at the line as desired as well as other places in the plant) technologies depending on what is required (Brooman, 1996). Each individual waste stream that cannot be prevented should be evaluated to determine its potential for effective recycle or resource recovery.

The decision on whether to purchase a recycle or resource recovery process should be based on several factors. Economic factors such as process operating costs and effluent disposal costs for the current system must be compared with those estimated for the new technology. The initial capital investment of the new technology along with any potential cost savings and the length of the payback period must also be considered. Other factors such as the characteristics of the waste stream(s) considered for treatment, the ability of the process to accept reused or recycled materials, and the effects of the recycle or recovery technology on the overall waste treatment process should also be considered.

The entire PWB manufacturing process must be considered when assessing the economic feasibility of a recycle or resource recovery process. An individual recovery process can recover copper from a single stream originating from the MHC process, or it may recover the metal from streams that originate from other processes as well. Only by considering the new technology's impact on the entire process, can an accurate and informed decision be made. While this section focuses on technologies that could be used to recycle or recover resources from the waste streams that are generated from the MHC process, many of these technologies are applicable to other PWB process lines. Workplace practices that can lead to the recycle or reuse of resources (e.g., manually recovering copper from panel racks, water recycle using cascade water rinse systems) are discussed in Section 6.1.

Reverse Osmosis

Reverse osmosis is a recovery process used by the PWB industry to regenerate rinse waters and to reclaim process bath drag-out for return to the process (EPA, 1990). It relies on a semi-permeable membrane to separate the water from metal impurities allowing bath solutions to be reused. It can be used as a recycling or recovery technology to reclaim or regenerate a specific solution, or it can be part of an overall waste treatment process to concentrate metals and impurities before final treatment.

The reverse osmosis process uses a semi-permeable membrane which permits only certain components to pass through it and a driving force to separate these components at a useful rate. The membrane is usually made of a polymer compound (e.g., nylon) with hole sizes ranging from 0.0004 to 0.06 microns in diameter. High pressure pumping of the waste stream, at pressures typically ranging from 300 to 1,500 pounds per square inch (psi) force the solution through the membrane (Capsule Environmental Engineering, Inc., 1993). The membrane allows the water to pass while inhibiting the metal ions, collecting them on the membrane surface. The concentrated metal ions are allowed to flow out of the system where they are reused as bath make-up solution or are sent to treatment. The relatively pure water can be recycled as rinse water or directly sewered.

The reverse osmosis process has some limitations. The types of waste streams suitable for processing are limited to the ability of the plastic membranes to withstand the destructive nature of the given waste stream. The membranes are sensitive to solutions with extreme pH values, either low or high, which can degrade the polymer membranes. Pure organic streams are likewise not treatable. Waste streams with suspended solids should be filtered prior to separation to keep the solids from fouling the membrane, thus reducing the efficiency of the process. Process membranes may also have a limited life due to the long-term pressure of the solution on the membrane (Coombs, 1993). Data regarding the usage of reverse osmosis technology by industry was not collected by the Pollution Prevention Survey.

Ion Exchange

Ion exchange is a process used by the PWB industry mainly to recover metal ions, such as copper or palladium, from rinse waters and other solutions. This process uses an exchange resin to remove the metal from solution and concentrate it on the surface of the resin. It is particularly suited to treating dilute solutions, because it removes the metal species from the solution instead of removing the solution from the metal. As a result, the relative economics of the process improve as the concentration of the feed solution decreases. Aside from recovering copper, ion exchange can also be used for treating wastewater, deionizing feed water, and recovering chemical solutions.

Ion exchange relies on special resins, either cationic or anionic, to remove the desired chemical species from solution. Cation exchange resins are used to remove positively charged ions such as copper. When a feed stream containing copper is passed through a bed of cation exchange resin, the resin removes the copper ions from the stream, replacing them with hydrogen ions from the resin. For example, a feed stream containing copper sulfate ($CuSO_4$) is passed through the ion exchange resin where the copper ions are removed and replaced by hydrogen ions to form sulfuric acid (H_2SO_4). The remaining water effluent is either further processed using an anion exchange resin and then recirculated into the rinse water system, or pH neutralized and then directly sewered. Ion exchange continues until the exchange resin becomes saturated with metal ions and must be regenerated.

Special chelating resins have been designed to capture specific metal ions that are in the presence of chelating agents, such as metal ions in electroless plating baths. These resins are effective in breaking down the chemical complexes formed by chelators that keep metal ions dissolved in solution, allowing them to be captured by the resin. They ignore hard water ions, such as calcium and magnesium that would otherwise be captured, creating a more pure concentrate. Chelating resins require that the feed stream be pH adjusted to reduce acidity and filtered to remove suspended solids that will foul the exchange bed (Coombs, 1993).

Regeneration of the cation or chelating exchange resin is accomplished using a moderately concentrated (e.g., ten percent) solution of a strong acid, such as sulfuric acid. Regeneration reverses the ion exchange process by stripping the metal ions from the exchange resin and replacing them with hydrogen ions from the acid. The concentration of metal ions in the remaining regenerant depends on the concentration of the acid used, but typically ranges from 10 to 40 g/L or more (Coombs, 1993).

Ionic exchange can be combined with electrowinning (electrolytic recovery) to recover metal from solutions that would not be cost-effective to recover using either technology alone. It can be used to concentrate a dilute solution of metal ions for electrolytic recovery that would otherwise be uneconomical to recover. For example, a dilute copper chloride solution can be treated by an ion exchange unit which is regenerated using sulfuric acid, producing a concentrated copper sulfate solution. The electrowinning unit can then be used to recover the copper from the solution while regenerating the acid, which could then be used for the next regeneration cycle.

A benefit of ion exchange is the ability to control the type of metallic salt that will be formed by selecting the type of acid used to regenerate the resin. In the previous example, the copper chloride was converted to copper sulfate while being concentrated by the ion exchange system. This is particularly useful when electrowinning is used, since it cannot process solutions containing the chlorine ion without generating toxic chlorine gas.

Twenty-six percent of the respondents to the Pollution Prevention Survey reported using an ion exchange process as a water recycle/chemical recovery technology. The average capital cost of a unit, which is related to its capacity, reported by the respondents was $47,500 with a low of $5,000 and a high of $100,000.

Electrolytic Recovery

Electrolytic recovery, also known as electrowinning, is a common metal recovery technology employed by the PWB industry. Operated either in continuous or batch mode, electrowinning can be applied to various process fluids including spent microetch, drag-out rinse water, and ion exchange regenerant. An advantage of electrowinning, which uses an electrolytic cell to recover dissolved copper ions from solution, is its ability to recover only the metal from solution without recovering the other impurities that are present. The recovered copper can then be sold as scrap or reused in the process.

Process waste solutions containing chlorine ions in any form should not be processed using electrolytic recovery methods since the electrolysis of these solutions could generate chlorine gas. Solutions containing copper chloride salts should first be converted using ion exchange methods to a non-chloride copper salt (e.g., copper sulfate) solutions before undergoing electrowinning to recover the copper content (Coombs, 1993).

Electrowinning is most efficient with concentrated solutions. Dilute solutions with less than 100 mg/L of copper become uneconomical to treat due to the high power consumption relative to the amount of copper recovered (Coombs, 1993). Waste streams that are to be treated should be segregated to prevent dilution and to prevent the introduction of other metal impurities. Already diluted solutions can be concentrated first using ion exchange or evaporation techniques to improve the efficiency and cost-effectiveness of metal recovery.

The electrolytic cell is comprised of a set of electrodes, both cathodes and anodes, placed in the copper laden solution. An electric current, or voltage, is applied across the electrodes and through the solution. The positively charged metal ions are drawn to the negatively charged cathode where they deposit onto the surface. The solution is kept thoroughly mixed using air agitation, or other proprietary techniques, which allow the process to use higher current densities (the amount of current per surface area of cathode) that speed deposition time and improve efficiency. As copper recovery continues, the concentration of copper ions in solution becomes depleted, requiring the current density to be reduced to maintain efficiency. When the concentration of copper becomes too low for its removal to be economically feasible, the process is discontinued and the remaining solution is sent to final treatment.

The layers of recovered copper can be sold as scrap to a metals reclaimer. Copper removal efficiencies of 90 to 95 percent have been achieved using electrolytic methods (EPA, 1990). The remaining effluent will still contain small amounts of copper and will be acidic in nature (i.e., low pH). Adjusting the pH may not be sufficient for the effluent to meet the standards of some POTW authorities; therefore, further treatment may be required.

Eighteen percent of the Pollution Prevention Survey respondents reported using electrowinning as a resource recovery technology with nearly all (89 percent) being satisfied. The median cost of a unit reported by the respondents was $15,000; however, electrowinning capital costs are dependant on the capacity of the unit.

6.2.2 Control Technologies

If the release of a hazardous material cannot be prevented or recycled, it may be possible to treat or reduce the impact of the release using a control technology. Control technologies are engineering methods that minimize the toxicity and volume of released pollutants. Most of these methods involve altering either the physical or chemical characteristics of a waste stream to isolate, destroy, or alter the concentration of target chemicals. While this section focuses on technologies that are used to control on-site releases from the MHC process, many of these technologies are also applicable to other PWB process lines.

Control technologies are typically used to treat on-site releases to both water and air from the operation of the MHC process. Wastewater containing concentrations of heavy metal ions, along with chelators and complexing agents, are of particular concern. Water effluent standards require the removal of most heavy metals and toxic organics from the plant effluent before it can be disposed to the sewer. On-site releases to air of concern include formaldehyde vapors, as well as acid and solvent fumes. The desire to eliminate both formaldehyde and chelating agents has led to the development of alternative MHC processes. This section identifies the control technologies used by PWB manufacturers to treat or control wastewater and air emissions released by the operation of the MHC process.

Wastewater Treatment

Chemical Precipitation. In the PWB industry, the majority of facilities surveyed (61 percent) reported using a conventional chemical precipitation system to accomplish the removal of heavy metal ions from wastewater. Chemical precipitation is a process for treating wastewater that depends on the water solubility of the various compounds formed during treatment. Heavy metal cations that are present in the wastewater are reacted with certain treatment chemicals to form metal hydroxides, sulfides, or carbonates that all have relatively low water solubilities. The resulting heavy metal compounds are then precipitated from the solution as an insoluble sludge that is subsequently recycled to reclaim the metals content or sent to disposal. The chemical precipitation process can be operated as a batch process, but is typically operated in a continuous process to treat wastewater.

In the chemical precipitation treatment of wastewater from PWB manufacturing, the removal of heavy metals may be carried out by a unit sequence of rapid mix precipitation, flocculation, and clarification. The process begins with the dispersion of treatment chemicals into the wastewater input stream under rapid mixing conditions. The initial mixing unit is designed to create a high intensity of turbulence in the reactor vessel, promoting encounters between the metal ions and the treatment chemical species, which then react to form metal compounds that are insoluble in water. The type of chemical compounds formed depends on the treatment chemical employed; this is discussed in detail later in this section. These insoluble compounds form a fine precipitate at low pH levels that remains suspended in the wastewater.

The wastewater then enters the flocculation tank. The purpose of the flocculation step is to transform smaller precipitation particles into large particles that are heavy enough to be removed from the water by gravity settling in the clarification step. This particle growth is accomplished in a flocculation tank using slow mixing to promote the interparticle collisions of precipitate particles suspended in the wastewater. The degree of flocculation is enhanced through the use of flocculating chemicals such as cationic or anionic polymers. These chemicals promote interparticle adhesion by adding charged particles to the wastewater that attach themselves to the precipitate, thereby increasing the growth rate of the precipitate particles.

Clarification is the final stage of the wastewater treatment process. The wastewater effluent from the flocculation stage is fed into a clarification tank where the water is allowed to collect undisturbed. The precipitate then settles out of the water by gravity, forming a blanket of sludge at the bottom of the clarification tank. A portion of the sludge, typically 10 to 25 percent, is often recirculated to the head of the flocculation step to reduce chemical requirements, as well as to enhance the rate of precipitation (Frailey, 1996). The sludge particles provide additional precipitation nuclei that increase the probability of particle collisions, resulting in a more dense sludge deposit. When a dense layer of sludge has been formed, the sludge is removed from the tank and is either dewatered or sent for recycle or disposal. The precipitate-free water is then either recycled or sewered.

Other process steps are sometimes employed in the case of unusually strict effluent guidelines. Filtration, reverse osmosis, ion exchange, or additional precipitation steps are sometimes employed to further reduce the concentration of chemical contaminants present in the wastewater effluent.

The heavy metal sludge generated by the wastewater treatment process is often concentrated, or dewatered, before being sent to recycle or disposal. Sludge can be dewatered in several methods including sludge thickening, press filtration, and sludge drying. Through the removal of water, sludge volume can be minimized, thus reducing the cost of disposal.

Treatment of Non-Chelated Wastewater. The absence of complexing chemicals (e.g., ammonia) or chelating agents (e.g., EDTA) in the wastewater stream simplifies the removal of heavy metal ions by precipitation. Heavy metal removal from such waste streams is accomplished through simple pH adjustment using hydroxide precipitation. Caustic soda (NaOH) is typically used while other treatment chemicals include calcium hydroxide and magnesium hydroxide. The heavy metal ions react with the caustic soda to form insoluble metal hydroxide compounds that precipitate out of solution at a high pH level. After the precipitate is removed by gravity settling, the effluent is pH adjusted to a pH of seven to nine and then sewered. The treatment can be performed in a chemical precipitation process similar to the one described above, resulting in a sludge contaminated with metals that is then sent to recycling or disposal.

Treatment of Wastewater Containing Chelated Metals. The presence of complexing chemicals or chelators require a more vigorous effort to achieve a sufficient level of heavy metal removal. Chelators are chemical compounds that inhibit precipitation by forming chemical complexes with the metals, allowing them to remain in solution beyond their normal solubility limits. These chemicals are found in spent MHC plating baths, in cleaners, and in the water effluent from the rinse tanks following these baths. Treatment chemicals enhance the removal of chelated metals from water by breaking the chelant-to-metal bond, destroying the soluble complex. The freed metal ions then react to form insoluble metal compounds, such as metal hydroxides, that precipitate out of solution. Several different chemicals are currently being used to effectively treat chelator-contaminated wastewater resulting from the manufacture of PWBs. Some common chemicals used in the treatment of wastewater produced by the MHC process are briefly described in Table 6.6. For a more information regarding individual treatment chemicals and their applicability to treating specific wastes, consult the supplier of the treatment chemical.

Table 6.6 Treatment Chemicals Used to Remove Heavy Metals From Chelated Wastewater

Chemical	Description
Ferrous Sulfate	Inexpensive treatment that requires iron concentrations in excess of 8:1 to form an insoluble metal hydroxide precipitate (Coombs, 1993). Ferrous sulfate is first used as a reducing agent to breakdown the complexed copper structures under acidic conditions before forming the metal hydroxide during subsequent pH neutralization. Drawbacks include the large volumes of sludge generated and the presence of iron which reduces the value of sludge to a reclaimer.
DTC (Dimethyl-dithiocarbamate)	Moderately expensive chemical that acts as a complexing agent, exerting a stronger reaction to the metal ion than the chelating agent, effectively forming an insoluble heavy metal complex. The sludge produced is light in density and difficult to gravity separate (Guess, 1992; Frailey, 1996).
Sodium Sulfide	Forms heavy metal sulfides with extremely low solubilities that precipitate even in the presence of chelators. Produces large volume of sludge that is slimy and difficult to dewater (Guess, 1992).
Polyelectrolyte	Polymers that remove heavy metals effectively without contributing to the volume of sludge. Primary drawback is the high chemical cost (Frailey, 1996).
Sodium Borohydride	Strong reducing agent reduces heavy metal ions which then precipitate out of solution forming a compact, low volume sludge. Drawbacks include its high chemical cost and the evolution of potentially explosive hydrogen gas (Guess, 1992; Frailey, 1996).
Ferrous Dithionite	Reduces heavy metal ions under acidic conditions to form metallic particles that are recovered by gravity separation. Excess iron is regenerated instead of being precipitated producing a low volume sludge (Guess, 1992).

Effects of MHC Alternatives On Wastewater Treatment. The strong desire to remove both formaldehyde and complexing chemicals, such as chelators, from the MHC process has led the drive away from traditional electroless copper and toward the development of alternative MHC processes. These processes eliminate the use of chelating agents that inhibit the precipitation of heavy metal ions in wastewater. Also eliminated is the need for expensive treatment chemicals, which are designed to breakdown chelators and which can add to the quantity of sludge produced. The resulting treatment of the non-chelated waste stream produces less sludge at a lower chemical treatment cost than it would if chelators were present. A detailed description of the treatment for both chelated and non-chelated wastes is presented elsewhere in this chapter.

While MHC alternative processes may reduce or eliminate the presence of chelators in the wastewater, they do not create any additional treatment concerns that would require any physical changes in the treatment process. The treatment of wastewater generated from the operation of a MHC alternative can be accomplished using the traditional chemical precipitation stages of rapid mix precipitation, flocculation, and clarification.

Alternative Treatment Processes. Although chemical precipitation is the most common process for treating wastewater by PWB manufacturers, other treatment processes exist as well. Survey respondents reported the use of both ion exchange (33 percent) and/or electrowinning (12 percent) to successfully treat wastewater generated from the manufacture of PWBs. These processes operate separately, or in combination, to efficiently remove heavy metal ions from chelated or non-chelated waste streams, typically yielding a highly concentrated sludge for disposal. These processes were discussed in Section 6.2.1.

Batch Treatment of Process Baths. Most spent process baths can be mixed with other wastewater and treated by the on-site wastewater treatment process using chemical precipitation. Chemical suppliers, however, recommend that some process baths be treated separately from the usual waste treatment process. The separate treatment of these baths is usually recommended due to the presence of strong chelating agents, high heavy metal concentrations, or other chemicals, such as additives or brighteners, that require additional treatment measures before they can be disposed of properly. Spent bath solution requiring special treatment measures can be processed immediately, but is typically collected and stored until enough has accumulated to warrant treatment. Batch treatment of the accumulated waste is then performed in a single tank or drum, following the specific treatment procedures provided by the chemical supplier for that bath.

Despite the supplier's recommendations, PWB facilities sometimes treat individual process baths using their typical wastewater treatment process. Spent bath solutions can be mixed slowly, in small quantities, with other wastewater before being treated, thus diluting the concentration of the chemical species requiring treatment. However, the introduction of concentrated wastes to the wastewater could result in increased treatment chemical consumption and more sludge produced than if batch treated separately. Also the introduction of a chemical species not typically found in the wastewater may adversely affect the treatment process or require more vigorous treatment chemicals or processes. Factors affecting the success of such treatment include the type of treatment chemicals used, the contaminant concentrations in the wastewater, and the overall robustness of the treatment process.

Air Pollution Control Technologies

Air pollution control technologies are often used by the PWB industry to cleanse air exhaust streams of harmful fumes and vapors. Exactly half (50 percent) of the PWB facilities surveyed have installed air scrubbers to control air emissions from various manufacturing processes, and almost a quarter of the facilities (23 percent) scrub air releases from the MHC process. The first step of any air control process is the effective containment of fugitive air emissions at their source of release. This is accomplished using fume hoods over the process areas from which the air release of concern is emanating. These hoods may be designed to continuously collect air emissions for treatment by one of the methods described below.

Gas Absorption. One method for removing pollutants from an exhaust stream is by gas absorption in a technique sometimes referred to as air scrubbing. Gas absorption is defined as the transfer of material from a gas to a contacting liquid, or solvent. The pollutant is chemically absorbed and dispersed into the solvent leaving the air free of the pollutant. The selection of an appropriate solvent should be based upon the liquid's solubility for the solute, and the cost of the liquid. Water is used for the absorption of water soluble gases while alkaline solutions are typically used for the absorption of acid gases. Air scrubbers are used by the PWB industry to treat wet process air emissions, such as formaldehyde and acid fumes, and emissions from other processes outside the MHC process.

Gas absorption is typically carried out in a packed gas absorption tower, or scrubber. The gas stream enters the bottom of the tower, and passes upward through a wetted bed of packing material before exiting the top. The absorbing liquid enters the top of the tower and flows downward through the packing before exiting at the bottom. Absorption of the air pollutants occurs during the period of contact between the gas and liquid. The gas is either physically or chemically absorbed and dispersed into the liquid. The liquid waste stream is then sent to water treatment before being discharged to the sewer. Although the most common method for gas absorption is the packed tower, other methods exist such as plate towers, sparged towers, spray chambers, or venturi scrubbers (Cooper, 1990).

Gas Adsorption. The removal of low concentration organic gases and vapors from an exhaust stream can be achieved by the process of gas adsorption. Adsorption is the process in which gas molecules are retained on the interface surfaces of a solid adsorbent by either physical or chemical forces. Activated carbon is the most common adsorbent but zeolites such as alumina and silica are also used. Adsorption is used primarily to remove volatile organic compounds from air, but is also used in other applications such as odor control and drying process gas streams (Cooper, 1990). In the MHC process it can be used to recover volatile organic compounds, such as formaldehyde.

Gas adsorption occurs when the vapor-laden air is collected and then passed through a bed of activated carbon, or another adsorbent material. The gas molecules are adsorbed onto the surface of the carbon, while the clean vapor-free air is exhausted from the system. The adsorbent material eventually becomes saturated with organic material and must be replaced or regenerated. Adsorbent canisters, which are replaced on a regular basis, are typically used to treat small gas flow streams. Larger flows of organic pollutants require packed beds of adsorbent material, which must be regenerated when the adsorbent becomes saturated (Cooper, 1990).

Regeneration of the adsorbent is typically accomplished by a steam stripping process. The adsorbent is contacted with low pressure steam which desorbs the adsorbed gas molecules from the surface of the packed bed. Following condensation of the steam, the organic material is recovered from the water by either decanting or distillation (Campbell, 1990).

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